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A proposal of criteria for the evaluation of industrial physical-plant utilization.

Gantz, Saxe Perry

Purdue University

A PROPOSAL OF CRITERIA FOR THE EVALUATION OF INDUSTRIAL

PHYSICAL-PLANT UTILIZATION

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Saxe Perry Gantz

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ABSTRACT

An extensive survey of the literature on plant layout was made. No quantative measures of evaluating plant layouts were encountered. From the considerations of good plant layout practice as found in the literature eleven measurable indices were developed and proposed as criteria of effective physical-plant utilization.

The criteria were applied to a small, newly formed plant in Indiana before and after a change in layout which was made to adopt methods and layout improvements. This demonstrated the applicability of the several indices to the plant in question, and demonstrated their use.

A critique of the eleven indices was made in which their applicability to continuous, intermittent, and jobbing layouts were discussed.

CONCLUSIONS AND RECOMMENDATIONS

Eleven indices of effective physical plant utilization have been proposed. One has been set aside as being of doubtful value. Of the remaining ten, all seem suitable and are recommended for evaluation of a continuous manufacturing layout with one considered to be of secondary importance. Three indices appear suitable and are recommended for evaluation of jobbing layouts. The intermittent plant may be evaluated by either three or ten indices depending upon whether it tools for continuous manufacture on some products. The employment of the indices as criteria of layout is recommended for:

Continuous Manufacture

1. Index of Indirect Materials Handling
2. Index of Direct Materials Handling
3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading

5. Secondary Index of Automatic Machinery Loading
6. Index of Flexibility
7. Index of Floor Area Loading Density
8. Index of Aisle Wastage
9. Time Index
11. Inventory Index

Jobbing

3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading
7. Index of Floor Area Loading Density

The indices, although presently usable, are significant only in comparing one layout of a plant with another of the same plant. There are no developed standards against which numerical values of the separate indices may be compared. Neither is there established any relative importance of the indices. It would seem, therefore, that a wide field of further study exists, namely - that of relative order of importance of the indices, and that of the importance of specific index values. Also, since improvements in industry must pay for themselves in dollars and cents, an appropriate area of investigation would be the correlation of the criteria indices against costs.

A PROPOSAL OF CRITERIA FOR THE EVALUATION OF INDUSTRIAL PHYSICAL-PLANT UTILIZATION

THE PROBLEM

It is a recognized fact that plant layout is an extremely important function of planners in modern day industry. Our problem here is: how do planners in all industries effect physical-plant utilization, and how can the effectiveness of their layouts be measured, rather than the consideration of any specific industry with its specific planners. We define plant layout as the physical arrangement of the productive facilities of a manufacturing enterprise. The arrangement of building interiors, machines, services and associated equipment are thus included.

GENERAL PROCEDURE

Much has been written on the subject of physical-plant utilization, or plant layout; but, so far as is known, there have been developed no measurable indices of the effectiveness of any plant layout. Accordingly, it is proposed herein to review what has been written on the subject in broad, general terms, briefly setting forth principles, ideas and helpful hints for informational purposes. We shall then undertake the development of measurable criteria for evaluating the effectiveness of any plant layout. It is then proposed to apply the criteria to an existing plant as an example of their application. Following will be a criticism of the criteria and a recommendation relative to those that presently seem useful and those that appear to require further study.

REVIEW OF LITERATURE

The following review of what has been written on plant layout is presented in sections by subject. This author makes no claim of complete coverage of everything ever written on plant layout but does attest to an intensive survey of the literature. For further information on each subject, the reader is referred to the bibliography by footnotes at the close of each section.

The Process Chart

Quoting Dr. Marvin E. Mundel, "Process Charts - Product Analysis are a graphic means of portraying the separable steps of the procedure involved in performing the necessary work required to modify a product from one stage of completion to another."

Use of the Process Chart - Product Analysis can be helpful and should be made as a preliminary in rearranging an existing plant, in laying out a new department in an existing plant, and in designing the layout of a new plant.

(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22)

Scale Layouts

A scale layout is a small model layout of a plant or of a portion thereof performed in two or three dimensions from which the layout

engineer visualizes and studies the arrangement of the plant. Scales commonly used are $\frac{1}{4}$" = 1 ft.; 3/8" = 1 ft.; and $\frac{1}{2}$" = 1 ft. The model layout is invariably executed as exactly to scale as possible.

The design of a plant layout is generally undertaken by means of a scale method. It is believed that some scale method must be used.

Templates. Templates are two dimensional models of machinery and service equipment cut exactly to scale portraying machinery and service equipment profiles as viewed from above.

The use of templates cut to scale for all machinery and then fitted onto a board representing the plant floor area is probably the most widely used method of arriving at a final layout design. The templates are fitted, juggled, and refitted until a layout that appears optimum to the layout engineer results.
(2, 3, 4, 7, 8, 10, 12, 13, 15, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39)

Scale Models. Scale models are small, three-dimensional replicas of machinery and service equipment made exactly to scale portraying machinery and service equipment realistically as viewed from any direction.

More and more industrial concerns are discarding the template method in favor of the use of true scale models. This allows a true three-dimensional model setup and is particularly useful in planning a layout where the building is more than one story high. Requirements are that the models must be durable, exactly scaled, recognizable, inexpensive, and light in color.
(2, 9, 10, 12, 19, 20, 22, 23, 24, 25, 26, 29, 32, 36, 40, 41, 42, 43, 44, 45, 46)

Use of Color. Where one machine is used in the manufacture of more than one part, it sometimes is helpful to use different colors on the same

template or model to represent the production time spent on each part. That is to say, a template 30% blue, 50% white, and 20% yellow could indicate those percentages of production time spent on three different parts.
(9, 47)

Photographs. It is considered good practice to photograph one scale layout before it is torn down and another one made. The photographs allow a comparison of two or more layouts and also can serve as a guide in arranging the actual machinery on the plant floor. If colors are used in the scale layouts, they should be light.
(25, 40)

Materials Handling

Materials handling is here defined as the handling incident to the movement of production materials from raw stores to the first operation station, from there to the next, and so on through the entire production process to finished stores. The handling ordinarily is performed by special non-production personnel and/or sometimes by special equipment.

Much has been written on the subject of materials handling. Suffice it to say that any materials handling cost is a loss since materials handling is a non-productive function. There are, however, ways of keeping this necessary evil at a minimum.

Machinery Arrangement. By arranging machines in order of operation sequence, a part in manufacture can be passed from tote box to adjacent tote box by machine operators, thus eliminating materials handling as such. To accomplish this, the old practice of grouping similar-type machines into departments or divisions must be done away with, although this also has other advantageous features.

Conveyors and Chutes. Mechanical conveyors and chutes for transporting materials from operation to operation are becoming more and more widely used. Layout engineers are availing themselves of the increased diversity of types offered for sale in present day markets. It is safe to say that a mechanical conveyor can be found to suit any materials handling problem. Many concerns have reported great savings with the installation of conveyor systems, several companies' savings being large enough to pay for the installations in the first year. The usual types now in use are electrical, hydraulic, and gravity-operated conveyors. For the several-story plant, a gravity feed from the top floor down is an opportunity for savings in materials handling costs of which more concerns could well afford to take advantage. Mechanical conveyors are a necessity in true mass production. (3, 5, 7, 8, 9, 10, 11, 15, 17, 18, 19, 20, 21, 22, 23, 27, 28, 32, 33, 34, 35, 36, 37, 38, 39, 42, 44, 48, 49, 51, 52, 53, 54, 55, 56, 57, 58, 59)

Normal Flow

By definition, normal flow means flow in accordance with the natural sequence of operations as determined by the nature of the production materials.

Quoting Allan H. Mogensen: "It is evident, of course, that the process itself will have a great deal to do with the design and layout of the plant, inasmuch as the raw materials pass in at one end of the plant, flow through a number of given processes, and emerge at the other end as finished products and by-products."

The DuPont nylon plants are excellent examples of industrial establishments where the process determines the design of the plant. The raw material

in liquid solution is pumped up to the fifth story at one end of the plant. From there the production material flows downward and forward to emerge at the other end of the plant as finished spools of nylon thread.
(2, 7, 19, 20, 22, 33, 35, 37, 38, 55)

Number of Machines

The machines spoken of here are defined as production machinery and equipment.

An important economic consideration in any layout is that of using multiple tooling wherever feasible in order to hold the number of machines to a minimum. In this way, machinery depreciation, a very important cost item in low volume production, can be held down.
(2, 22, 60)

Multi-Machine Operation

We define multi-machine operation as the case where one person operates two or more production machines alternately, unloading and loading one while the other or others are operating.

Where machine time represents the greater part of a work cycle, savings can be realized by grouping two or more machines together for the use of one operator. A Man and Multi-Machine Time Chart should be made and used as a guide in this undertaking. This chart is a graphic means of portraying the work an operator performs when working with machines where the work of the machines is a controlling factor.
(1, 2, 7, 11, 22, 28, 54, 61)

Machine Movability

Machine movability is the capacity of machines to be moved without undue effort, cost, or waste of time. It implies the mere setting of machines on the floor without cementing in and/or bolting down.

It is particularly desirable in intermittent and in continuous manufacturing plants where there are periodic model changes in the manufactured product to have plant machinery readily movable. For example, the Spicer Manufacturing Company of Toledo once moved an average of twenty machines per week. Machine movability requires adequate plug-ins for electricity and adequate compressed air, water, and sewage connections. In addition, machines must be provided with their own transformers, controllers, and flexible cable connections.
(2, 19, 21, 22, 37, 38, 39, 53, 55, 56, 62, 63)

Floor Space

In speaking of plant floor space, we mean the floor area which is housed in that part of the plant devoted to production installations.

Floor space, since it is inside a building by definition, is costly and should therefore be conserved. There are two avenues open leading to space conservation. One is arranging machinery compactly while the other is elimination of unnecessary aisles. In some peculiar western plants, the plant floors are not roofed over. Necessarily the same principles apply.
(2, 10, 11, 18, 19, 20, 22, 28, 32, 35, 44, 50, 58)

Number of Stories

The number of stories here referred to is that in the plant proper where production facilities are housed.

There are advantages to be found in one story plant buildings and in multi-story buildings. The usual ones listed are:

<u>Single Story</u>.

1. Easy to expand by additions.
2. Heavy floor loading possible throughout plant.
3. Easier foundation requirements.
4. More natural light and air available.
5. Easy to rearrange layout of plant.
6. No floor space wasted on elevators and stairs.
7. Materials handling costs are less.
8. Lower cost per square foot of floor area.

<u>Multi-Story</u>.

1. Smaller area of land used.
2. Cheaper to heat.
3. Lower building maintenance cost.
4. Use of gravity feed allowed.
5. Upper stories free of dirt and street noise.
6. Easier to build on a hill side.

(2, 4, 10, 11, 19, 20, 22, 33, 34, 35, 36, 37, 39, 58, 60)

THE PROPOSAL OF CRITERIA

From a consideration of the foregoing review of literature, the following eleven indices are proposed as factors of importance in plant layout. Since they are measurable and in all respects readily obtainable, they are herewith offered as criteria for evaluating physical-plant utilization. An effort has been made to arrange or weight the factors of each of the first ten indices in such a manner that their individual calculated values will be fractional, approaching unity as maximum. The eleventh index will invariably be greater than unity.

It will be readily apparent to industrial engineers that all of the following proposed indices do not necessarily apply to any given industrial layout. It is believed, however, that all of them could apply to some layouts, and that most of them will apply to most layouts.

1. Index of Indirect Materials Handling $= \frac{a}{b}$

where a = The sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling

and b = The total actual distance a part moves via the production route from raw stores to finished stores

The fact that materials handling costs are losses and the recommended methods for eliminating them suggested this index, since it measures the ratio of the distance a production part moves automatically to the total distance the part moves.

In the numerator of the formula, the term "external materials handling" is construed to mean movement of production materials in boxes from one location to another by any person, whether he be a machine operator or a materials handling employee. The denominator represents the total distance

a part moves in the production process from raw stores to the first operation station, from there to the next, and so on, until it reaches finished stores.

The formula was placed in this form because the index value approaches one as external materials handling is reduced.

The index becomes a criterion of plant layout because it is a measure of the efficiency of the elimination of materials handling from particular production paths. A high index value indicates that a part moves through the production process mostly by conveyors, chutes, or common finished parts - raw parts locations, while a low value indicates that the part is mostly moved by non-producing personnel.

2. Index of Direct Materials Handling $= \frac{c}{b}$

where c = The direct line distance via the plant floor from raw stores to finished stores

and b = The total actual distance a part moves via the production route from raw stores to finished stores

This index was suggested by the same considerations as was the previous index. It should be noted that the Index of Indirect Materials Handling deals with the efficiency with which a production route is covered while the Index of Direct Materials Handling is concerned with how that route is laid out.

The numerator of the formula is intended to be the straight-line measure of distance from raw stores to finished stores by way of the plant floor. Where materials enter at one end of the building and emerge at the other, it will be the straight through distance. For an L-shaped plant, it will be the L distance and so on. The denominator is merely the measure of the complete length of the actual production path.

The formula was arranged in its particular form because its theoretical maximum approaches unity.

a part moves in the production process from raw stores to the first operation station, from there to the next, and so on, until it reaches finished stores.

The formula was placed in this form because the index value approaches one as complete automatic handling is reached.

The index becomes a criterion of plant layout because it is a measure of the efficiency of the elimination of materials handling from particular production paths. A high index value indicates that a part moves through the production process mostly by conveyors, chutes, or common finished parts - raw parts locations, while a low value indicates that the part is mostly moved by non-production personnel.

5. Index of Direct Materials Handling $= \frac{D}{T}$

Where D = the direct line distance via the plant floor from raw stores to finished stores

and T = the total actual distance a part moves via the production route from raw stores to finished stores

This index was suggested by the same considerations as was the previous index. It should be noted that the Index of Indirect Materials Handling deals with the efficiency with which a production route is covered while the Index of Direct Materials Handling is concerned with how the route is laid out.

The numerator of the formula is intended to be the straight-line measure of distance from raw stores to finished stores by way of the plant floor. Where materials enter at one end of the building and emerge at the other, it will be the straight through distance. For an L-shaped plant, it will be the L distance and so on. The denominator is merely the measure of the complete length of the actual production path.

The formula was arranged in its particular form because its theoretical maximum approaches unity.

For the denominator to be reduced to a value near that of the numerator of the formula, the machines of a plant, will, of necessity, have to be arranged in operation sequence from raw stores in a direct line toward finished stores, thus eliminating external materials handling.

The above index is, therefore, considered a criterion of efficient plant layout since it is a measure of the efficiency with which the production route covers the distance from raw to finished stores.

3. Index of Gravity Utilization $= \frac{d}{e}$

where d = The sum of the vertical distance gravity feed used

and e = The total vertical distance up a part moves from raw stores to finished parts

The suggestion of using gravity as a conveyor actuator under materials handling in the review of literature suggested the index of gravity utilization.

Ideally, a part lifted up from the main floor of the plant should be returned thereto alone by the force of gravity without having to expend further materials handling in the process. Should this obtain, the value of the above index approaches one.

The above index is offered as a criterion of plant layout because it measures the efficiency with which gravity is used in returning to the main floor parts lifted therefrom.

4. Prime Index of Automatic Machinery Loading $= \frac{f}{100g}$

where f = The sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles

and g = The total number of operators on those machines

This index was suggested by the subject of multi-machine operation.

By down time is meant the portion of the work cycle where the machine is unloaded and reloaded in the manner that an automatic lathe would be. This index can be used only for machinery where the machine time portion of the over-all work cycle is automatic and the machines may be left unattended while operating. The factor of 100 was placed in the denominator to preserve the fractional value because the numerator is the sum of percentages.

The above index measures the efficiency of grouping machines for multi-machine operation and is, therefore, considered a criterion of good layout. If there are too many operators for the machines, the index value will be low and will increase as more machines are operated by fewer operators. Note that only machines with 50 percent down time or less are used, since these offer an easier opportunity for grouping and it was desired to have this index measure, on a large scale, the effectiveness with which this was done.

5. Secondary Index of Automatic Machinery Loading $= \frac{h}{100g}$

where h = The sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of the individual work cycles

and g = The total number of operators on those machines

This is a measure of the success of solving the more difficult problem of grouping machines whose down time is such as to create the need for odd combinations of machines and men.

6. Index of Flexibility $= \frac{j}{k}$

where j = The number of machines capable of being moved to a new location in the production line in one working shift

and k = The total number of machines in the production line

Index of flexibility was suggested by consideration of the desirable features of having machines readily movable.

The components of the formula are self-explanatory.

Since the index measures the fraction of the total number of machines readily movable in a plant, it here is offered as a criterion of plant layout.

7. Index of Floor Area Loading Density = $\dfrac{\Sigma\left[(m + 2)\ (n + 2)\ + p\right]}{q - r}$

where m = Extreme machine length in feet

n = Extreme machine width in feet

p = Operator work area in square feet

q = Total plant floor area in square feet

and r = Total aisle area in square feet

This index was suggested by consideration of the floor space conservation suggestion of the literature dealing with compact machinery arrangement on the plant floor.

A glance at the numerator of the formula reveals that it is the sum of the profile areas of machines as viewed from above with a one-foot wide clear space around each and with the operator work spaces added in. The one-foot clear space is provided as an addition to the profile areas by necessity since common practice allows at least two feet between adjacent machines for their servicing. The term machines in the formula includes all production machinery including conveyors that rest on or near the floor but excludes overhead conveyors which pass over and clear of other machinery. The denominator of the formula is the sum of the floor area of the plant available for the locating of machinery. Aisles are excluded from available plant floor area by definition and are treated in the index following.

The formula is arranged in its above form so that a heavy floor loading density will give a greater index value than a light loading, and also, an index value of one represents perfect floor area loading.

The index, as calculated by the formula, is offered as a criterion because it represents a measure of the efficiency with which the plant floor area is used. A high value of the index results from close, compact arrangement of machinery, while a low value indicates loose and spread out spacing.

8. Index of Aisle Wastage $= \frac{q - r}{q}$

where $q =$ Total plant floor area

and $r =$ Total aisle area

This index was suggested by consideration of floor space conservation through elimination of unnecessary aisles.

Aisle area represents floor area not available for active production and is, therefore, an item to be minimized.

Since the index yields a value representing the fractional part of the total plant floor area available for placement of production machinery, it is here considered a criterion of plant layout.

9. Time Index $= \frac{s}{t}$

where $s =$ The sum of the standard times for all operations on a part

and $t =$ The total standard times for the part, raw stores to finished stores including handling time and time in banks

This index was not suggested by any specific principle of plant layout, rather it was conceived from an understanding of the general problems of plant layout.

The numerator of the formula, being the sum of the standard time for operations on a part, represents the total time the part should be actively worked on in production. The denominator yields the total time the part should be in process from start to finish of the production process. Note that standard times are used. This eliminates consideration of operator

efficiency and reduces the index to a function solely of a plant layout.

The formula was placed in the above form in order that its maximum value could approach unity.

Materials handling and the banking of parts while in production are plant layout problems. Since this index measures the time efficiency with which a part traverses the production process, it is offered here as a plant layout criterion. A low index value indicates that a part wastes time idling in temporary storage along the production process (a high in process inventory value) while a high index value indicates that the part moves smoothly and steadily along the production route, (a low in process inventory value).

10. Index of Human Comfort $= \frac{u + v + w}{3}$

where u = Factor from Table 1

v = Factor from Table 2

and w = Factor from Table 3

Table 1

Operator Work Space

Smallest Dimension of Available Area in Which Operator Performs His Work	Factor
30 inches and above	1.00
29 inches	.90
28 inches	.80
27 inches	.70
26 inches	.60
25 inches	.50
24 inches	.40
23 inches	.30
22 inches	.20
21 inches	.10
20 inches and below	0.0

Table 2

Work Place Temperature

Degrees Fahrenheit	Factor
110° and above	.0
105°	.10
100°	.25
95°	.50
90°	.70
85°	.80
80°	.90
75°	.95
70°	1.00
65°	.90
60°	.80
55°	.60
50°	.40
45°	.20
40° and below	.00

Table 3

Lighting of Work Area

Foot Candles for Occupations A-E as Listed Below					Factor
A	B	C	D	E	
5	10	20	55	100 and above	1.00
4	8	17	45	85	.75
3	6	14	35	70	.50
2	4	11	25	55	.25
1	2	8	15	40 and below	.00

A. Warehouses, aisles, stairways, passageways.
B. Rough assembly, general indoor construction, grinding, locker rooms, glass blowing, plating, power plants, elevators.
C. General manufacturing, textile mills, machine shops, fine assembly, bakeries, canning, general painting, polishing, proof reading, class rooms, general offices.
D. Extra fine grading and sorting, cutting, polishing and inspecting glass, offices doing fine work, drafting rooms.
E. Extra fine assembly such as jewelry, watch and instrument making, dark goods manufacture, extra fine machine work, engraving, linotype, monotype.

The Index of Human Comfort was not conceived by any special regard for plant layout principles. Numerous volumes, however, have been written on the subject of employer-employee relationships which discuss at length the fact that industry of today, to survive, must consider labor to consist of fellow human beings rather than to exist as a commodity. Of all of management's complex problems in dealing with labor one falls directly upon the layout engineer. That is the layout of the worker's work area. There are three fundamental components thereof. They are the physical area in which a worker is confined in performing his tasks, the light which he has to work by, and the temperature of the area in which he works. Factor values were assigned in Tables 1, 2 and 3 above in accordance with previously determined standards.

11. Inventory Index $= \frac{x}{y}$

where x = The rate of production

and y = Time index

This index does not approach unity as a maximum. It measures the number of production units planned for the production line at any one time. It is offered here as being of use since any materials tied up in the process of production represent an investment, sometimes costly, from which no returns are realized. Every effort should be made to reduce to absolute minimum the "in production inventory".

Reviewing the components of the preceding eleven indices it is readily apparent that they are easily obtainable and measurable quantities. They are:

a - The sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling

b - The total actual distance a part moves via the production route from raw stores to finished stores

c - The direct line distance via the plant floor from raw stores to finished stores

d - The sum of the vertical distance gravity feed used

e - The total vertical distance up a part moves from raw stores to finished parts

f - The sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles

g - The total number of operators on those machines

h - The sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of the individual work cycles

j - The number of machines capable of being moved to a new location in the production line in one working shift

k - The total number of machines in the production line

m - Extreme machine length in feet

n - Extreme machine width in feet

p - Operator work area in square feet

q - Total plant floor area in square feet

r - Total aisle area in square feet

s - The sum of the standard times for all operations on a part

t - The total standard times for the part, raw stores to finished stores including handling time and time in banks

u - A tabled area factor value

v - A tabled temperature factor value

w - A tabled lighting factor value

x - The rate of production

y - Time index

APPLICATION OF CRITERIA TO EXISTING PLANT

In searching for a plant to which to apply the developed criteria of effective plant layout, a small, newly formed plant in west central Indiana was chosen. It is a plant that began production of tub, basin and sink valve fixtures only recently. Starting with five employees the plant has mushroomed without benefit of layout techniques to where it now employees fifty people.

Not long ago the plant made some changes in layout in an effort to adopt some recommended methods and layout improvements. Figure 1 is a photograph of a block template layout before the change and Figure 2 that after the change.

Fig. 1 Template Layout of Plant, Initial Layout

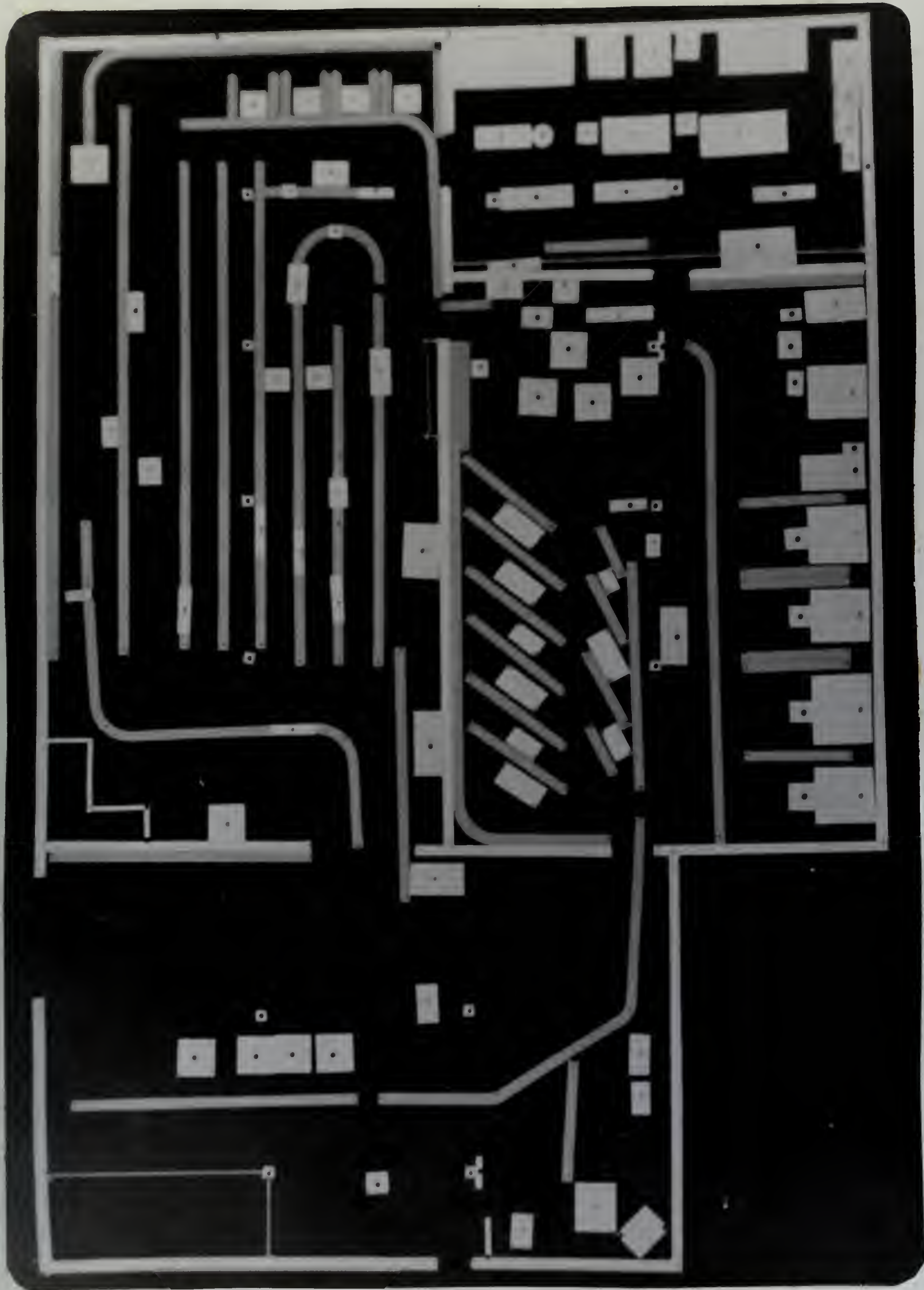


Fig. 2 Template Layout of Plant, Improved Layout

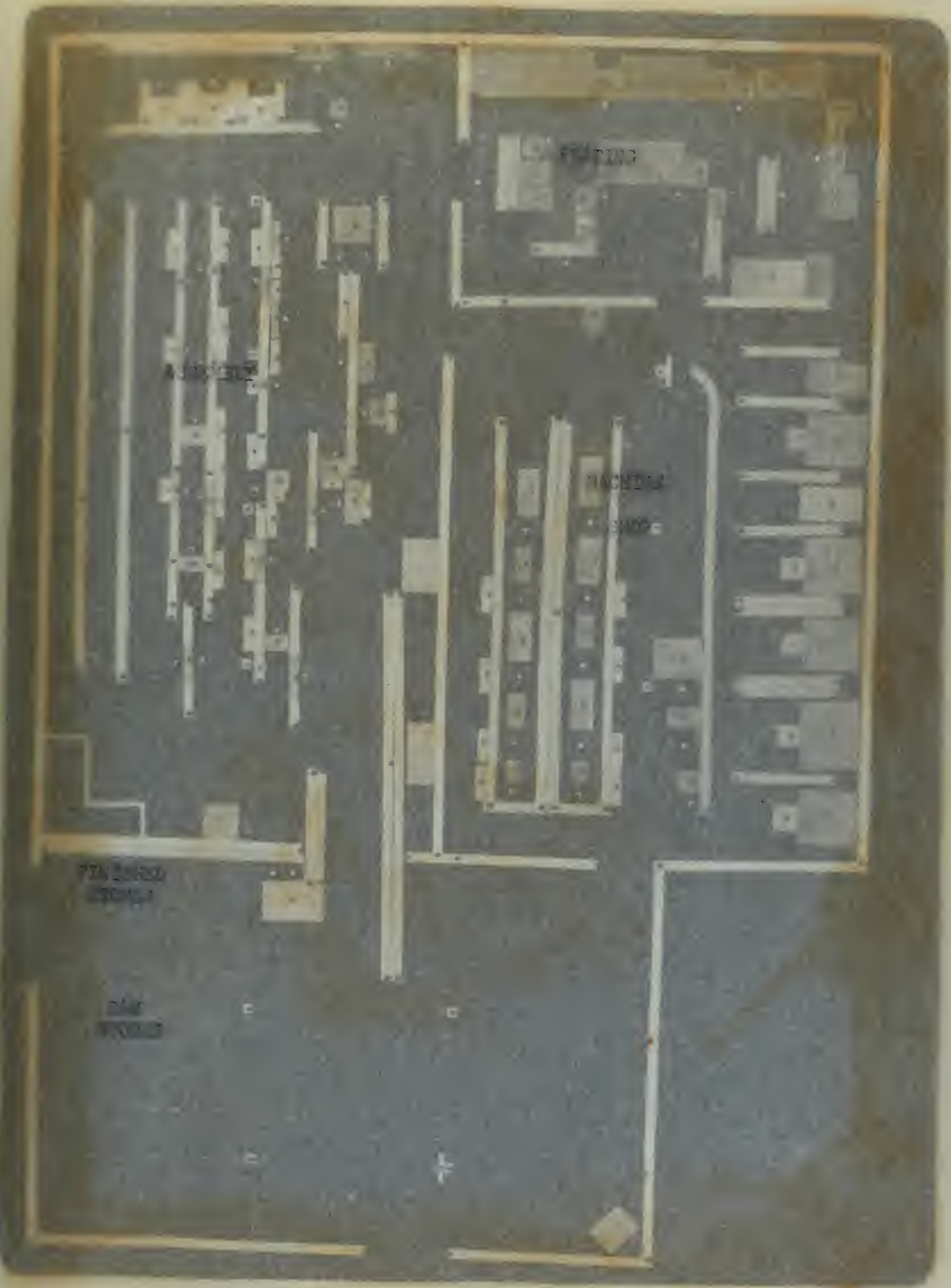
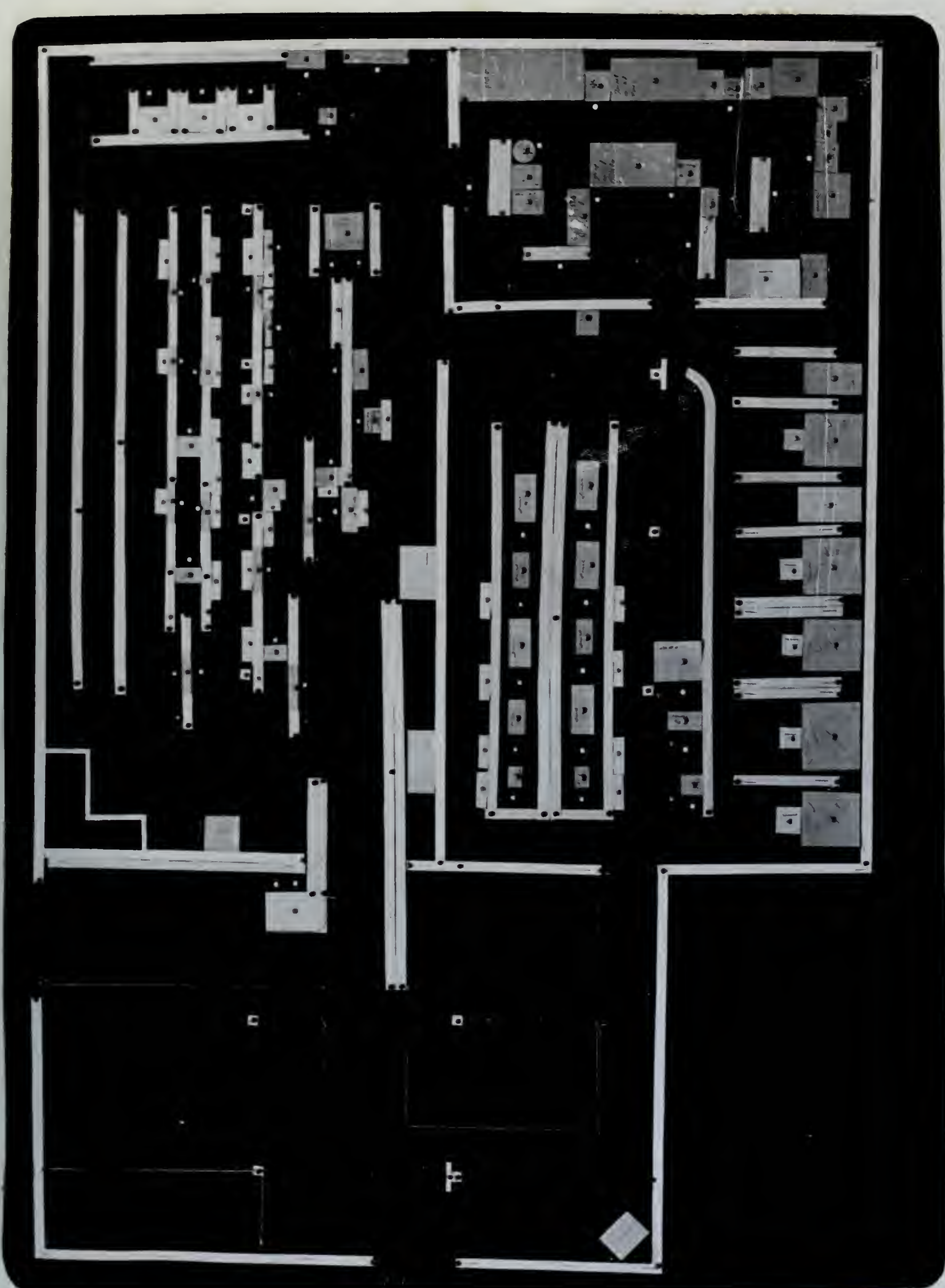


Fig. 2 Template Layout of Plant, Improved Layout



Two valves, numbers 308 and 280 were chosen as typical production because these two comprise approximately 80% of total production. Criteria measurements were made before and after the layout changes and, where different, they appear below in the computation of indices.

1. Index of Indirect Materials Handling $= \frac{a}{b}$

where a = The sum of the distances a part moves automatically by conveyor and from machine to machine arranged in operation sequence without external materials handling

and b = The total actual distance a part moves via the production route from raw stores to finished stores

	Initial Layout	Changed Layout
Valve 308	a = 0	a = 42 ft.
	b = 343 ft.	b = 264 ft.
Index	$= \frac{0}{343} = 0$	$= \frac{42}{264} = .16$
Valve 280	a = 0	a = 40 ft.
	b = 576 ft.	b = 303 ft.
Index	$= \frac{0}{576} = 0$	$= \frac{40}{303} = .13$

Valves 308 and 280 consist of many parts, but the main part, however, is the valve body which passes along the complete production line and is joined at various points along the line by the other parts. Quantities a and b were therefore measured for the valve body from raw stores through the production route, including assembly of all other parts to the body, and on until the finished valve was packaged and delivered to finished stores.

Although several hundred feet of roller conveyors were installed in the plant, they were not used initially for the usual purpose intended, and much of the conveyor length was used for storage of parts. The change in

layout included slanting some sections of the conveyor thus providing real values for quantity a. Throughout the rest of the distance operators stop working to move materials from station to station.

2. Index of Direct Materials Handling $= \frac{c}{b}$

where c = The direct line distance via the plant floor from raw stores to finished stores

and b = The total actual distance a part moves via the production route from raw stores to finished stores

	Initial Layout	Changed Layout
Valve 308	c = 216 ft.	c = 216 ft.
	b = 343 ft.	b = 264 ft.
	Index $= \frac{216}{343} = .63$	Index $= \frac{216}{264} = .82$
Valve 280	c = 216 ft.	c = 216 ft.
	b = 576 ft.	b = 303 ft.
	Index $= \frac{216}{576} = .38$	Index $= \frac{216}{303} = .71$

As in the preceding index, valve body travel distances were used in measuring quantity b. Quantity c was measured from raw stores through the machine shop in a straight line, on into and through assembly in an L path and on to finished stores.

The increases of the index in the changed layout reflects the shortened production route established by the change.

3. Index of Gravity Utilization $= \frac{d}{e}$

where d = The sum of the vertical distance gravity feed used

and e = The total vertical distance up a part moves from raw stores to finished parts

	Initial Layout	Changed Layout
Valve 308 and 280	d = 0	d = 2
	e = $7\frac{1}{2}$	e = $7\frac{1}{2}$
	Index $= \frac{0}{7\frac{1}{2}} = 0$	Index $= \frac{2}{7\frac{1}{2}} = .27$ approx.

In the initial layout quantity d was zero, but it has a real value in the new layout because of the tilting of the roller conveyors to provide automatic materials handling. The valve materials are lifted to roller conveyor height once going into the machine shop and once going into assembly.

4. Prime Index of Automatic Machinery Loading $= \frac{f}{100\ g}$

where f = The sum of the percentages of machine down time from all cases where the individual percentages of down time are equal to or less than 50% of the individual work cycles

and g = The total number of operators on those machines

This index and the one following have no value because the plant under consideration has no automatic machinery.

5. Secondary Index of Automatic Machinery Loading $= \frac{h}{100\ g}$

where h = The sum of the percentages of machine down time from all cases where the individual percentages of down time are greater than 50% of the individual work cycles

and g = The total number of operators on those machines

6. Index of Flexibility $= \frac{j}{k}$

where j = The number of machines capable of being moved to a new location in the production line in one working shift

and k = The total number of machines in the production line

Initial and Changed Layout

$$j = 35$$
$$k = 48$$
$$\text{Index} = \frac{35}{48} = .73$$

The plant surveyed has a total of 48 machines of which 13 are fixed and 35 are capable of being moved. The index has the same value for both layouts because the change did not alter the machinery equipment of the plant.

7. Index of Floor Area Loading Density $= \frac{\sum\left[(m + 2)\ (n + 2) + p\right]}{q - r}$

where m = Extreme machine length in feet

n = Extreme machine width in feet

p = Operator work area in square feet

q = Total plant floor area in square feet

r = Total aisle area in square feet

Initial Layout	Changed Layout
Index $= \frac{3350.5}{5142} = .65$	Index $= \frac{3208.5}{4712} = .68$

In the interest of presenting only figures of importance herein, the individual values of m, n, p, q and r are not listed. Several pages would be required to record all their values since there are a total of 48 machines and many aisles.

It is to be noted that the new layout has reduced the value of the numerator of the index formula. This was caused by the elimination of unnecessary roller conveyor. Also note that the denominator of the new layout index has been reduced. The new layout spaced the lines more compactly and thus opened up more area which for lack of better use exists as aisles.

8. Index of Aisle Wastage $= \frac{q - r}{q}$

where q = Total plant floor area in square feet

and r = Total aisle area in square feet

Initial Layout	Changed Layout
q = 6400 sq. ft.	q = 6400 sq. ft.
r = 1257.5 sq. ft.	r = 1687.5 sq. ft.
Index $= \frac{5142.5}{6400} = .80$	Index $= \frac{4712.5}{6400} = .75$

Interestingly enough, the layout change decreased the value of this index. The improvement eliminated waste production space by more compact

arrangements which showed up as an increase in aisle area. Actually this represents area available for production machinery which is exactly what we desire the index to tell us.

9. Time Index $= \frac{s}{t}$

where s = The sum of the standard times for all operations on a part

and t = The total standard times for the part, raw stores to finished stores including handling time and time in banks

	Initial Layout	Changed Layout
Valve 308	s = .10207 hr.	s = .10207 hr.
	t = 6.87815 hr.	t = 3.49011 hr.
	Index $= \frac{.10207}{6.87815} = .0148$	Index $= \frac{.10207}{3.49011} = .0292$
Valve 280	s = .12123 hr.	s = .12123 hr.
	t = 8.16498 hr.	t = 4.14310 hr.
	Index $= \frac{.02123}{8.16498} = .0149$	Index $= \frac{.12123}{4.14310} = .0293$

As previously, the valve bodies were used as the basis of the above computations. Standard times for all operations on the valve body through machining, assembly and packaging were used.

It is noted that the layout change in both cases nearly doubled the index value. Even with the change, however, an extremely low index value exists indicating that the bank and handling standard times are all out of proportion to the operation standard times. This makes for a very high in process inventory which should be reduced.

10. Index of Human Comfort $= \frac{u + v + w}{3}$

where u = A tabled area factor value

$$v = \text{A tabled temperature factor value}$$

and $w =$ A tabled lighting factor value

All of the workers at the plant under study had more than sufficient working room in both layouts.

The temperature in winter is kept at or near 70° F and in summer it depends, of course, on the local weather conditions. Since the plant is exceptionally well ventilated it should not become appreciably warmer than the outside. Arbitrarily an average of 70° F is assigned.

Footcandle light meter readings were taken at 23 different locations throughout the plant morning and afternoon on cloudy days. No worker receives less light than would score a factor of 1.0 and the overall average of all the readings was 38.3 foot candles. The classification of the type work done at the plant is that listed for C in Table 3.

The above index in consequence of the foregoing is computed as follows:

From Tables 1, 2, and 3

$$u = 1$$

$$v = 1$$

$$w = 1$$

$$\text{Index} = \frac{1 + 1 + 1}{3} = 1.0$$

11. Inventory Index $= \frac{x}{y}$

where $x =$ The rate of production

and $y =$ Time index

Since the plant surveyed is still operating sporadically, no rates of production can yet be established and consequently no inventory index can be computed. From the very low values of the Time Index it is seen that the Inventory Index would take on a very high value if computed.

CRITIQUE

1. <u>The Index of Indirect Materials Handling</u>. This index appears to be sound, easily computed, and usable in any plant employing conveyors and/or sequential operation layouts. The latter consideration would probably confine the usefulness of this index to continuous manufacturing plants or to intermittent plants which tool up to manufacture continuously on large orders.

2. <u>The Index of Direct Materials Handling</u>. The same criticism as above applies to this index since the only way to obtain a very high index value is to align the production machinery sequentially in a direct line from raw stores to finished stores.

3. <u>The Index of Gravity Utilization</u>. This index appears to be sound, easily computed, and a valuable measure in any plant whether intermittent or continuous. It should be particularly useful in evaluating the layout of a multi-story concern.

4. <u>The Prime Index of Automatic Machinery Loading</u>. This index is believed to be a reasonable measure of the efficiency with which automatic machinery is arranged for operation by less than one person per machine. Accordingly it belongs in the field of plant layout evaluation criteria wherever automatic machinery is employed.

5. <u>The Secondary Index of Automatic Machinery Loading</u>. Essentially the same criticism as for the Prime Index holds true for this index. It can be used effectively to determine machine-man loading efficiency in odd cases such as the operation of 4 machines by 3 men. Since it is usable only for such odd cases, which are rare, it is believed to be of secondary value in plant layout evaluation.

6. The Index of Flexibility. The flexibility index appears easily usable in any plant, continuous or intermittent, where machines are moved into assembly lines for a specific product and which are rearranged to accommodate changes in product design. Accordingly it appears to be a sound index of layout evaluation for such plants.

7. The Index of Floor Area Loading Density. Since this index effectively measures efficiency of floor use it is held to be a criterion of layout. Fault may well be taken with the arbitrary assignment of machine profile area in a horizontal plane bordered by a one foot clear space as one measure in determination of the index. It can be argued that some large machines require extra area for loading and/or for repairs. The factors in the formula for the index were assigned because a start must be made at some place. A truer index would result from the "necessary" machine floor area divided by that portion of the total plant floor area available for machinery. This index serves intermittent, continuous or job shop layouts alike.

8. The Index of Aisle Wastage. Aisles serve two purposes - the movement of men and the movement of materials. In a theoretically perfect mass production layout where each work piece automatically proceeds from machine to machine, no aisles would be necessary, provided that reasonable access to work stations existed for personnel. In such a case this index takes on its maximum value. Note, however, that one condition is complete automatic materials handling. Such conditions would give Index 1, the Index of Indirect Materials Handling, a value of unity. Accordingly high correlation may exist between these two indices. The Index of Aisle Wastage does appear to be sound, simple to calculate, and of value as a layout criterion, especially in continuous and intermittent manufacture.

9. The Time Index. This index seems of use only in continuous or specially tooled up intermittent plants. It is a strong indication of the time efficiency of travel of a part through the production process. As such it not only becomes a measure of plant layout but also of production control. The Time Index is believed to be a particularly powerful tool for evaluation of layouts.

10. The Index of Human Comfort. This index is believed to be of doubtful value in spite of the importance to the worker of the three components - heat, light and work area. With no light to work in, yet with adequate space and proper temperature, an individual score could be .67. Trouble arises also in taking averages of many values because it is the individual case that needs to be corrected when an unsatisfactory condition does exist. Although the components are individually of great importance, there appears to be no justification for combining them into one index or even of using them as individual indices. Accordingly this index, the Index of Human Comfort, is set aside.

11. The Inventory Index. This index takes on equal importance with the time index and is, of course, based on the time index. It tells immediately the number of production units planned for the production line. As such it quickly detects over banking and poor materials handling. Obviously this index is usable only in continuous manufacture, but can be used in an intermittent plant set up for continuous work on one or more products.

CONCLUSIONS AND RECOMMENDATIONS

Eleven indices of effective physical plant utilization have been proposed. One has been set aside as being of doubtful value. Of the remaining ten, all seem suitable and are recommended for evaluation of a continuous manufacturing layout with one considered to be of secondary importance. Three indices appear suitable and are recommended for evaluation of jobbing layouts. The intermittent plant may be evaluated by either three or ten indices depending upon whether it tools for continuous manufacture on some products. The employment of the indices as criteria of layout is recommended for:

Continuous Manufacture

1. Index of Indirect Materials Handling
2. Index of Direct Materials Handling
3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading
5. Secondary Index of Automatic Machinery Loading
6. Index of Flexibility
7. Index of Floor Area Loading Density
8. Index of Aisle Wastage
9. Time Index
11. Inventory Index

Jobbing

3. Index of Gravity Utilization
4. Prime Index of Automatic Machinery Loading
7. Index of Floor Area Loading Density

The indices, although presently usable, are significant only in comparing one layout of a plant with another of the same plant. There are no developed standards against which numerical values of the separate indices may be compared. Neither is there established any relative importance of the indices. It would seem, therefore, that a wide field of further study exists, namely - that of relative order of importance of the indices, and that of the importance of specific index values. Also, since improvements in in-

dustry must pay for themselves in dollars and cents, an appropriate area of investigation would be the correlation of the criteria indices against costs.

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c.2 A proposal of criteria
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